

# Supplementary Information

## Tree height and leaf drought tolerance traits shape growth responses across droughts in a temperate broadleaf forest

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### List of Tables

1	Table S1. Monthly Palmer Drought Severity Index (PDSI), and its rank among all years between 1950 and 2009 (driest=1), for focal droughts. . . . .	3
2	Table S2. Species-specific regression equations for bark thickness (mm) as a function of diameter at breast height without bark (mm). . . . .	4
3	Table S3. Species-specific regression equations for height (m) as a function of DBH (cm) . . .	5
4	Table S4. Individual tests of species traits as drivers of drought resistance, where $Rt$ is used as the response variable. . . . .	6
5	Table S5. Individual tests of species traits as drivers of drought resistance, where $Rt_{ARIMA}$ is used as the response variable. . . . .	7
6	Table S6. Individual tests of species traits as drivers of drought recovery ( $Rc$ ). . . . .	8
7	Table S7. Individual tests of species traits as drivers of drought resilience ( $Rs$ ). . . . .	9
8	Table S8. Summary of top full models for each drought instance, where $Rt$ is used as the response variable. . . . .	10
9	Table S9. Summary of top models for each drought instance, where $Rt_{ARIMA}$ is used as the response variable. . . . .	11
10	Table S10. Summary of top models for each drought instance, where $Rc$ is used as the response variable. . . . .	12
11	Table S11. Summary of top models for each drought instance, where $Rs$ is used as the response variable. . . . .	13

### List of Figures

1	<b>Figure S1. Time series of Palmer Drought Severity Index (PDSI) for each focal drought year <math>\pm</math> 2 years</b> . . . . .	14
2	<b>Figure S2. Map of ForestGEO plot showing topographic wetness index and location of cored trees.</b> Scale units are in meters . . . . .	15

3	<b>Figure S3. Distribution of reconstructed tree heights across drought years.</b>	16
4	<b>Figure S4. Distribution of independent variables by species.</b> Species that are assigned the same letter are not significantly different from each other with regard to the tested variable.	17
5	<b>Figure S5. Comparison of <math>Rt</math> and <math>Rt_{ARIMA}</math> results, with residuals, for each drought scenario</b>	18
6	<b>Figure S6. Drought recovery, <math>Rc</math>, across species for the three focal droughts.</b>	19
7	<b>Figure S7. Drought recovery, <math>Rc</math>, across species for the three focal droughts.</b>	20
<b>Appendix S1. Further Package Citations</b>		

Table S1. Monthly Palmer Drought Severity Index (PDSI), and its rank among all years between 1950 and 2009 (driest=1), for focal droughts.

year	month	PDSI	rank
1966	May	-2.98	2
	June	-3.40	2
	July	-4.08	2
	August	-4.82	1
1977	May	-2.96	3
	June	-3.28	3
	July	-3.61	3
	August	-3.68	3
1999	May	-3.63	1
	June	-4.21	1
	July	-4.53	1
	August	-4.64	2

Table S2. Species-specific regression equations for bark thickness (mm) as a function of diameter at breast height without bark (mm).

Species	Equations	$R^2$
<i>Carya cordiformis</i>	$\ln[r_{bark}] = -1.56 + 0.416 * \ln[DBH]$	0.226
<i>Carya glabra</i>	$\ln[r_{bark}] = -0.393 + 0.268 * \ln[DBH]$	0.04
<i>Carya ovalis</i>	$\ln[r_{bark}] = -2.18 + 0.651 * \ln[DBH]$	0.389
<i>Carya tomentosa</i>	$\ln[r_{bark}] = -0.477 + 0.301 * \ln[DBH]$	0.297
<i>Fagus grandifolia</i>	-	-
<i>Fraxinus americana</i>	$\ln[r_{bark}] = 0.418 + 0.268 * \ln[DBH]$	0.256
<i>Juglans nigra</i>	$\ln[r_{bark}] = 0.346 + 0.279 * \ln[DBH]$	0.246
<i>Liriodendron tulipifera</i>	$\ln[r_{bark}] = -1.14 + 0.463 * \ln[DBH]$	0.545
<i>Quercus alba</i>	$\ln[r_{bark}] = -2.09 + 0.637 * \ln[DBH]$	0.603
<i>Quercus prinus</i>	$\ln[r_{bark}] = -1.31 + 0.528 * \ln[DBH]$	0.577
<i>Quercus rubra</i>	$\ln[r_{bark}] = -0.593 + 0.292 * \ln[DBH]$	0.101
<i>Quercus velutina</i>	$\ln[r_{bark}] = 0.245 + 0.219 * \ln[DBH]$	0.087

We used linear regression on log-transformed data to relate  $r_{bark}$  to the diameter inside bark from 2008 data. These were then used to determine  $r_{bark}$  in the  $DBH_Y$  reconstruction (DBH in year Y). No bark correction was applied for *Fagus grandifolia*, which has thin bark.

Table S3. Species-specific regression equations for height (m) as a function of DBH (cm)

Species	Equations	$R^2$
Carya cordiformis	$\ln[H] = 0.332 + 0.808 * \ln[DBH]$	0.874
Carya glabra	$\ln[H] = 0.685 + 0.691 * \ln[DBH]$	0.841
Carya ovalis	$\ln[H] = 0.533 + 0.741 * \ln[DBH]$	0.924
Carya tomentosa	$\ln[H] = 0.726 + 0.713 * \ln[DBH]$	0.897
Fagus grandifolia	$\ln[H] = 0.708 + 0.662 * \ln[DBH]$	0.857
Liriodendron tulipifera	$\ln[H] = 1.33 + 0.52 * \ln[DBH]$	0.771
Quercus alba	$\ln[H] = 0.74 + 0.645 * \ln[DBH]$	0.719
Quercus prinus	$\ln[H] = 0.41 + 0.757 * \ln[DBH]$	0.886
Quercus rubra	$\ln[H] = 1.00 + 0.574 * \ln[DBH]$	0.755
all	$\ln[H] = 0.839 + 0.642 * \ln[DBH]$	0.857

Table S4. Individual tests of species traits as drivers of drought resistance, where  $Rt$  is used as the response variable.

variable	category	all droughts		1966		1977		1999	
		$\Delta AICc$	coefficients	$\Delta AICc$	coefficients	$\Delta AICc$	coefficients	$\Delta AICc$	coefficients
xylem porosity	R	-0.8	0.0630	2.29**	0.190	1.92	-0.152	3.36**	0.1500
	D/SR		0.0000		0.000		0.000		0.0000
$PLA$		6.7**	-0.0140	9.13**	-0.025	-0.32	-0.010	-0.95	-0.0070
$LMA$		-2.01	0.0002	-1.9	0.001	-1.68	-0.002	-2.03	0.0003
$\pi_{tlp}$		1.33	-0.1740	-1.65	-0.107	1.23	-0.245	-0.1	-0.1690
$WD$		-1.97	-0.0310	-1.26	-0.206	-1.44	-0.154	0.66	0.2720

Variable abbreviations are as in Table 2.  $\Delta AICc$  is the  $AICc$  of a model excluding the trait minus that of the model including it.

\*\* $\Delta AICc > 2$ : variable considered significant as an individual predictor

Table S5. Individual tests of species traits as drivers of drought resistance, where  $Rt_{ARIMA}$  is used as the response variable.

variable	category	all droughts		1966		1977		1999	
		$\Delta AICc$	coefficients	$\Delta AICc$	coefficients	$\Delta AICc$	coefficients	$\Delta AICc$	coefficients
xylem porosity	R	-1.47	0.0420	0.95	0.1520	2.84**	-0.171	2.27**	0.155
	D/SR		0.0000		0.0000		0.000		0.000
<i>PLA</i>		4.48**	-0.0120	10.15**	-0.0240	-0.9	-0.008	-1.67	-0.005
<i>LMA</i>		-1.99	-0.0003	-2.02	0.0005	-0.42	-0.003	-1.9	0.001
$\pi_{tlp}$		0.42	-0.1510	-1.94	-0.0530	-0.53	-0.179	0.04	-0.200
<i>WD</i>		-1.94	-0.0390	-0.08	-0.3040	-1.57	-0.142	0.83	0.316

Variable abbreviations are as in Table 2.  $\Delta AICc$  is the AICc of a model excluding the trait minus that of the model including it.

\*\* $\Delta AICc > 2$ : variable considered significant as an individual predictor

Table S6. Individual tests of species traits as drivers of drought recovery ( $Re$ ).

variable	category	all droughts		1966		1977		1999	
		$\Delta AICc$	coefficients	$\Delta AICc$	coefficients	$\Delta AICc$	coefficients	$\Delta AICc$	coefficients
xylem porosity	R	15.25**	-0.280	9.9**	-0.474	-1.67	-0.0370	17.06**	-0.3380
	D/SR		0.000		0.000		0.0000		0.0000
$PLA$		-1.98	0.002	-1.33	0.014	1.10	-0.0090	-2.03	0.0010
$LMA$		-1.35	-0.002	0.32	-0.008	-2.04	-0.0001	-2.03	-0.0005
$\pi_{tlp}$		-1.13	-0.149	-1.94	-0.101	1.08	-0.1630	-1.14	-0.2020
$WD$		-1.86	-0.088	-1.6	0.278	-1.68	-0.0980	-1.03	-0.2950

Variable abbreviations are as in Table 2.  $\Delta AICc$  is the  $AICc$  of a model excluding the trait minus that of the model including it.

\*\* $\Delta AICc > 2$ : variable considered significant as an individual predictor



Table S7. Individual tests of species traits as drivers of drought resilience ( $Rs$ ).

variable	category	all droughts		1966		1977		1999	
		$\Delta AICc$	coefficients	$\Delta AICc$	coefficients	$\Delta AICc$	coefficients	$\Delta AICc$	coefficients
xylem porosity	R	0.24	-0.147	-1.29	-0.110	1.42	-0.263	-1.11	-0.0840
	D/SR		0.000		0.000		0.000		0.0000
<i>PLA</i>		1.09	-0.016	1.09	-0.020	-0.51	-0.017	0.67	-0.0130
<i>LMA</i>		-1.9	-0.001	-1.00	-0.004	-1.95	-0.001	-2.02	-0.0004
$\pi_{tlp}$		2.5**	-0.347	-1.11	-0.212	1.57	-0.468	6.11**	-0.3730
<i>WD</i>		-1.83	-0.109	-2.05	-0.020	-1.37	-0.298	-2.02	0.0360

Variable abbreviations are as in Table 2.  $\Delta AICc$  is the  $AICc$  of a model excluding the trait minus that of the model including it.

\*\* $\Delta AICc > 2$ : variable considered significant as an individual predictor

Table S8. Summary of top full models for each drought instance, where  $Rt$  is used as the response variable.

drought	$\Delta AICc$	$Marginal R^2$	$Conditional R^2$	Intercept	$\ln[H]$	$\ln[TWI]$	$\ln[H] * \ln[TWI]$	$PLA$	$\pi_{tp}$
<b>all</b>	<b>0.000</b>	<b>0.08</b>	<b>0.12</b>	<b>1.131</b>	<b>-0.057</b>	<b>-0.086</b>	-	<b>-0.012</b>	<b>-0.113</b>
	0.583	0.06	0.11	1.423	-0.055	-0.086	-	-0.013	-
	0.726	0.08	0.12	1.537	-0.202	-0.326	0.082	-0.012	-0.114
	1.352	0.06	0.11	1.826	-0.198	-0.324	0.081	-0.013	-
<b>1966</b>	<b>0.000</b>	<b>0.16</b>	<b>0.25</b>	<b>1.622</b>	<b>-0.135</b>	-	-	<b>-0.025</b>	-
<b>1977</b>	<b>0.000</b>	<b>0.06</b>	<b>0.22</b>	<b>0.503</b>	-	<b>-0.144</b>	-	-	<b>-0.24</b>
	0.908	0.01	0.21	1.069	-	-0.144	-	-	-
	0.988	0.06	0.22	0.568	-0.03	-0.139	-	-	-0.246
	1.144	0.08	0.24	0.684	-	-0.142	-	-0.007	-0.204
	1.267	0.04	0.22	1.211	-	-0.141	-	-0.01	-
<b>1999</b>	<b>0.000</b>	<b>0.01</b>	<b>0.18</b>	<b>1.061</b>	-	<b>-0.102</b>	-	-	-
	0.023	0.04	0.19	0.659	-	-0.101	-	-	-0.169
	0.954	0.02	0.19	1.157	-	-0.1	-	-0.007	-
	1.513	0.05	0.21	0.783	-	-0.1	-	-0.005	-0.145
	1.803	0.01	0.18	1.024	0.013	-0.103	-	-	-
	1.901	0.04	0.19	0.635	0.011	-0.102	-	-	-0.166

Models are ranked by AICc. Shown are all models whose AICc value falls within 2.0 ( $\Delta AICc < 1$ ) of the best model (bold).  $R^2$  refers to conditional  $R^2$ . Year was included in the model for all drought years, but its effect was not included in any top models, and coefficients were small (1966: 0, 1977: -0.019, 1999: -0.005; same values in all top models).

Table S9. Summary of top models for each drought instance, where  $Rt_{ARIMA}$  is used as the response variable.

drought	$\Delta AICc$	$Marginal R^2$	$Conditional R^2$	Intercept	$\ln[H]$	$\ln[TWI]$	$\ln[H] * \ln[TWI]$	$PLA$	$\pi_{tlp}$
<b>all</b>	<b>0.000</b>	<b>0.05</b>	<b>0.09</b>	<b>2.113</b>	<b>-0.307</b>	<b>-0.506</b>	<b>0.14</b>	<b>-0.012</b>	-
	0.419	0.06	0.10	1.872	-0.31	-0.508	0.141	-0.011	-0.096
	1.217	0.05	0.09	1.395	-0.06	-0.1	-	-0.012	-
	1.698	0.06	0.10	1.153	-0.062	-0.1	-	-0.011	-0.095
<b>1966</b>	<b>0.000</b>	<b>0.17</b>	<b>0.23</b>	<b>1.660</b>	<b>-0.154</b>	-	-	<b>-0.024</b>	-
	1.393	0.17	0.23	1.735	-0.152	-0.047	-	-0.024	-
	1.457	0.16	0.23	1.859	-0.152	-	-	-0.025	0.078
<b>1977</b>	<b>0.000</b>	<b>0.01</b>	<b>0.16</b>	<b>1.130</b>	-	<b>-0.18</b>	-	-	-
	0.424	0.02	0.16	2.453	-0.461	-0.896	0.25	-	-
	0.688	0.03	0.17	0.720	-	-0.179	-	-	-0.173
	0.922	0.04	0.17	2.040	-0.466	-0.898	0.251	-	-0.18
	0.927	0.03	0.17	1.248	-	-0.177	-	-0.008	-
	1.322	0.03	0.17	2.569	-0.461	-0.893	0.25	-0.008	-
	1.709	0.01	0.15	1.183	-0.02	-0.177	-	-	-
<b>1999</b>	<b>0.000</b>	<b>0.04</b>	<b>0.20</b>	<b>0.563</b>	-	<b>-0.076</b>	-	-	<b>-0.2</b>
	0.064	0.03	0.19	0.421	-	-	-	-	-0.202
	0.127	0.00	0.18	1.036	-	-0.077	-	-	-
	0.256	0.00	0.18	0.899	-	-	-	-	-
	1.777	0.04	0.20	0.529	0.016	-0.078	-	-	-0.195
	1.797	0.01	0.20	1.101	-	-0.076	-	-0.004	-
	1.815	0.00	0.18	0.986	0.018	-0.079	-	-	-
	1.838	0.01	0.20	0.972	-	-	-	-0.005	-
	1.933	0.03	0.19	0.391	0.012	-	-	-	-0.199
	1.979	0.04	0.21	0.612	-	-0.075	-	-0.002	-0.19
	1.999	0.04	0.21	0.482	-	-	-	-0.002	-0.19

Models are ranked by AICc. Shown are all models whose AICc value falls within 2.0 ( $\Delta AICc < 1$ ) of the best model (bold).  $R^2$  refers to conditional  $R^2$ . Year was included in the model for all drought years and apperaed in all its top models, but coefficients were small (1966: 0, 1977: -0.03, 1999: 0.008; same values in all top models).

Table S10. Summary of top models for each drought instance, where  $R_c$  is used as the response variable.

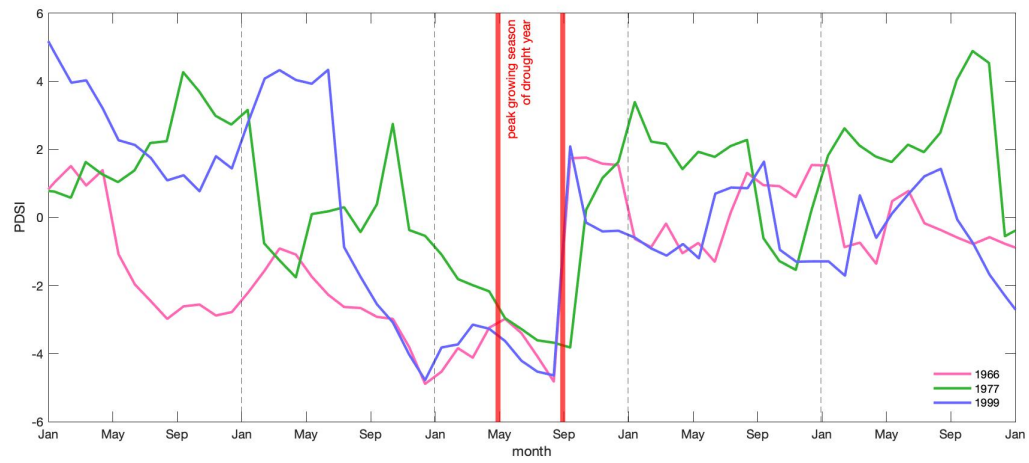
drought	$\Delta AICc$	$Marginal R^2$	$Conditional R^2$	Intercept	$\ln[H]$	$\ln[TWI]$	$\ln[H] * \ln[TWI]$	$PLA$	$\pi_{tlp}$
<b>all</b>	<b>0.000</b>	<b>0.05</b>	<b>0.17</b>	<b>0.434</b>	<b>0.345</b>	<b>0.844</b>	<b>-0.269</b>	-	-
	0.995	0.05	0.17	1.913	-0.126	-	-	-	-
	1.135	0.06	0.17	0.077	0.344	0.845	-0.269	-	-0.152
	1.991	0.05	0.18	0.410	0.346	0.843	-0.269	0.002	-
<b>1966</b>	<b>0.000</b>	<b>0.01</b>	<b>0.28</b>	<b>-0.797</b>	<b>0.89</b>	<b>1.263</b>	<b>-0.475</b>	-	-
	1.040	0.00	0.25	1.577	-	-	-	-	-
	1.367	0.02	0.30	-0.984	0.888	1.257	-0.474	0.013	-
	1.785	0.00	0.26	1.781	-	-0.114	-	-	-
	1.956	0.01	0.30	-1.025	0.89	1.261	-0.475	-	-0.097
<b>1977</b>	<b>0.000</b>	<b>0.17</b>	<b>0.17</b>	<b>2.485</b>	<b>-0.482</b>	-	-	-	<b>-0.157</b>
	0.299	0.17	0.17	2.943	-0.47	-	-	-0.008	-
	0.716	0.17	0.18	2.657	-0.477	-	-	-0.006	-0.114
	0.807	0.17	0.18	1.152	0.071	1.026	-0.308	-0.009	-
	0.875	0.17	0.18	2.729	-0.47	0.124	-	-0.009	-
	0.891	0.17	0.18	2.271	-0.479	0.115	-	-	-0.158
	0.910	0.17	0.18	0.712	0.054	1.004	-0.304	-	-0.159
	1.315	0.17	0.18	0.871	0.065	1.023	-0.308	-0.006	-0.112
	1.331	0.16	0.17	2.805	-0.464	-	-	-	-
	1.372	0.17	0.18	2.445	-0.475	0.122	-	-0.006	-0.112
	1.974	0.16	0.17	2.597	-0.466	0.118	-	-	-
<b>1999</b>	<b>0.000</b>	<b>0.00</b>	<b>0.16</b>	<b>1.281</b>	-	-	-	-	-
	0.532	0.00	0.17	1.093	-	0.105	-	-	-
	1.091	0.02	0.19	0.779	-	-	-	-	-0.212
	1.609	0.02	0.19	0.578	-	0.106	-	-	-0.217
	1.755	0.00	0.17	1.200	0.027	-	-	-	-
	1.996	0.00	0.18	1.251	-	-	-	0.002	-

Models are ranked by AICc. Shown are all models whose AICc value falls within 2.0 ( $\Delta AICc < 1$ ) of the best model (bold).  $R^2$  refers to conditional  $R^2$ . Year was included in the model for all drought years and appeared in all its top models (1966: 0, 1977: -0.14, 1999: -0.217; same values in all top models).

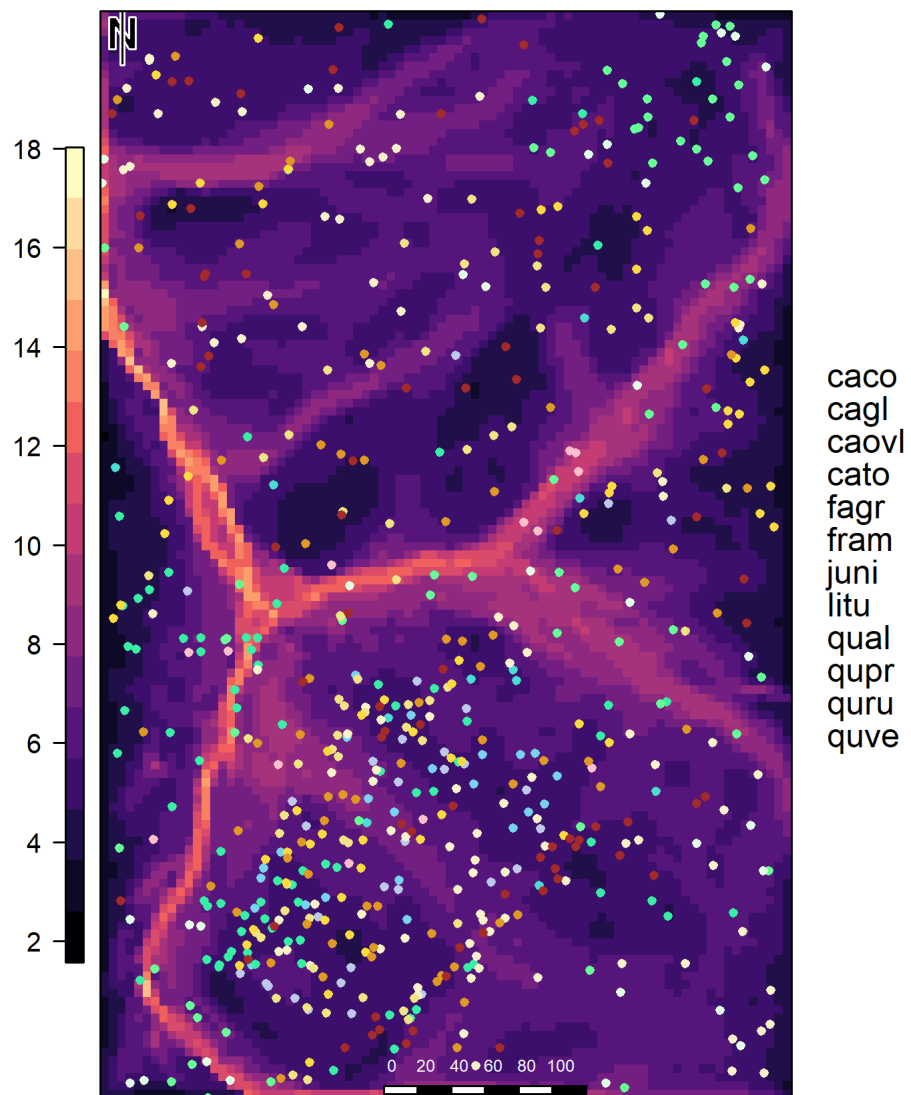
Table S11. Summary of top models for each drought instance, where  $R_s$  is used as the response variable.

drought	$\Delta AICc$	$Marginal R^2$	$Conditional R^2$	Intercept	$\ln[H]$	$\ln[TWI]$	$\ln[H] * \ln[TWI]$	$PLA$	$\pi_{up}$
<b>all</b>	<b>0.000</b>	<b>0.10</b>	<b>0.17</b>	<b>-0.265</b>	<b>0.348</b>	<b>0.864</b>	<b>-0.291</b>	<b>-0.012</b>	<b>-0.287</b>
	0.176	0.08	0.16	-0.572	0.347	0.859	-0.291	-	-0.347
	1.518	0.07	0.16	0.458	0.354	0.866	-0.292	-0.016	-
	1.552	0.09	0.17	1.253	-0.166	-	-	-0.011	-0.288
	1.698	0.08	0.16	0.940	-0.166	-	-	-	-0.348
<b>1966</b>	<b>0.000</b>	<b>0.04</b>	<b>0.15</b>	<b>1.834</b>	<b>-0.085</b>	-	-	<b>-0.02</b>	-
	0.402	0.03	0.16	1.589	-	-	-	-0.02	-
	1.189	0.00	0.14	1.534	-0.082	-	-	-	-
	1.313	0.00	0.15	1.293	-	-	-	-	-
	1.692	0.04	0.16	1.534	-0.085	-	-	-0.018	-0.116
<b>1977</b>	<b>0.000</b>	<b>0.14</b>	<b>0.28</b>	<b>-0.932</b>	<b>0.294</b>	<b>1.207</b>	<b>-0.384</b>	-	<b>-0.467</b>
	0.497	0.13	0.28	1.194	-0.383	-	-	-	-0.469
	1.304	0.15	0.30	-0.648	0.294	1.208	-0.383	-0.011	-0.411
	1.542	0.13	0.28	1.026	-0.387	0.095	-	-	-0.472
	1.555	0.09	0.28	0.138	0.304	1.211	-0.385	-	-
<b>1999</b>	1.852	0.14	0.29	1.467	-0.381	-	-	-0.01	-0.416
	<b>0.000</b>	<b>0.07</b>	<b>0.13</b>	<b>0.237</b>	-	-	-	-	<b>-0.366</b>
	0.313	0.08	0.14	0.472	-	-	-	-0.008	-0.317
	0.503	0.07	0.13	0.358	-0.048	-	-	-	-0.376
	0.532	0.07	0.13	0.394	-	-0.086	-	-	-0.364
	0.726	0.09	0.14	0.588	-0.047	-	-	-0.008	-0.328
	1.079	0.09	0.15	0.602	-	-0.081	-	-0.008	-0.319
	1.249	0.07	0.13	0.495	-0.044	-0.08	-	-	-0.374
	1.706	0.09	0.14	0.699	-0.044	-0.075	-	-0.007	-0.329

Models are ranked by AICc. Shown are all models whose AICc value falls within 2.0 ( $\Delta AICc < 1$ ) of the best model (bold).  $R^2$  refers to conditional  $R^2$ . Year was included in the model for all drought years and appeared in all its top models (1966: 0, 1977: -0.099, -0.099, -0.099, -0.097, -0.097; 1999: -0.174, -0.174, -0.174, -0.173, -0.172).



**Figure S1.** Time series of Palmer Drought Severity Index (PDSI) for each focal drought year  $\pm 2$  years



**Figure S2.** Map of ForestGEO plot showing topographic wetness index and location of cored trees. Scale units are in meters

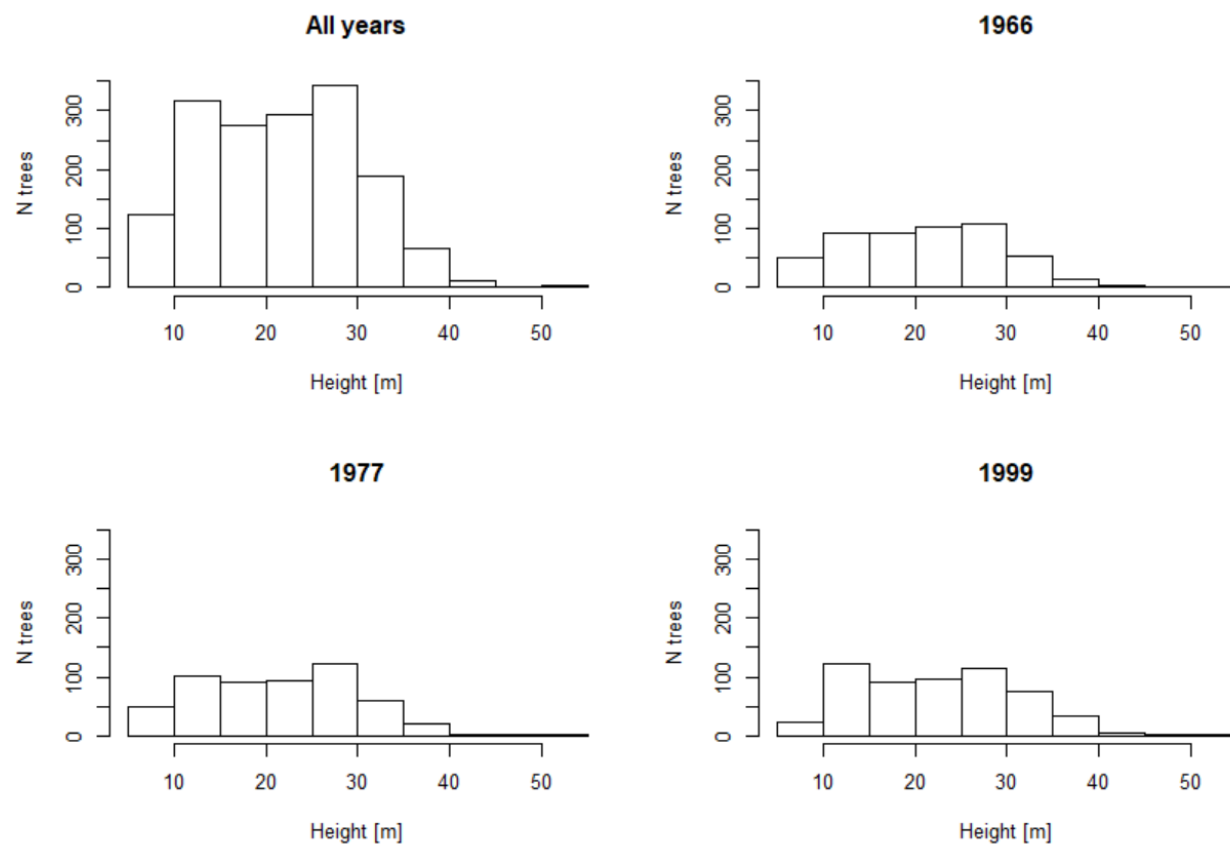
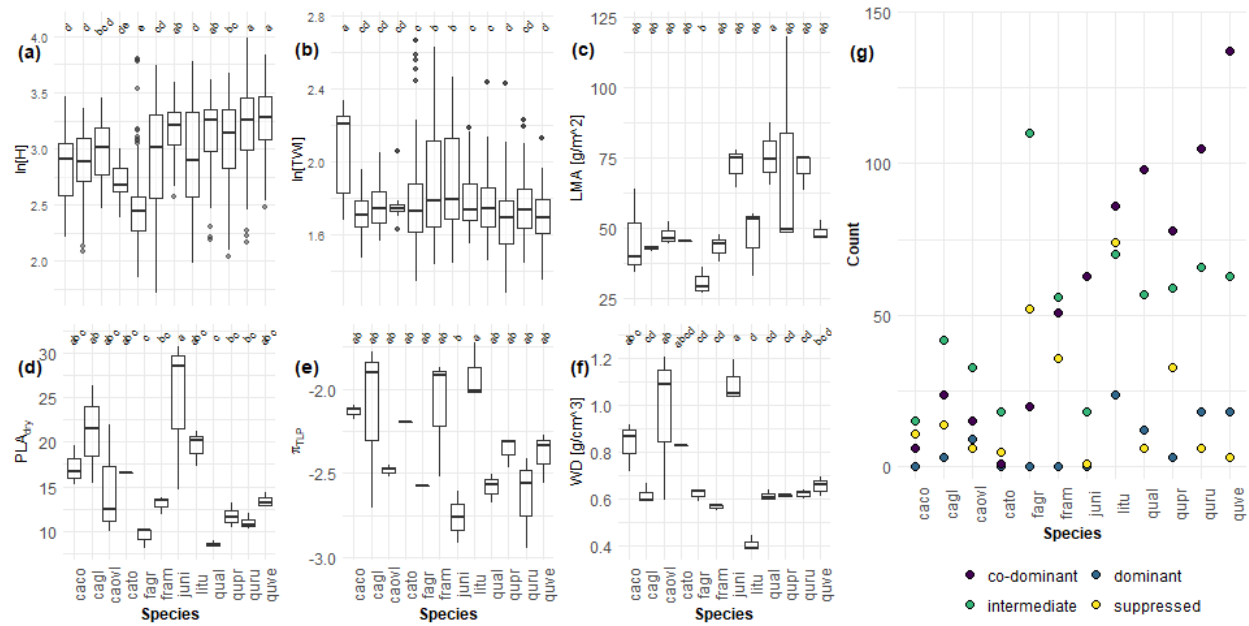


Figure S3. Distribution of reconstructed tree heights across drought years.





**Figure S4. Distribution of independent variables by species.** Species that are assigned the same letter are not significantly different from each other with regard to the tested variable.

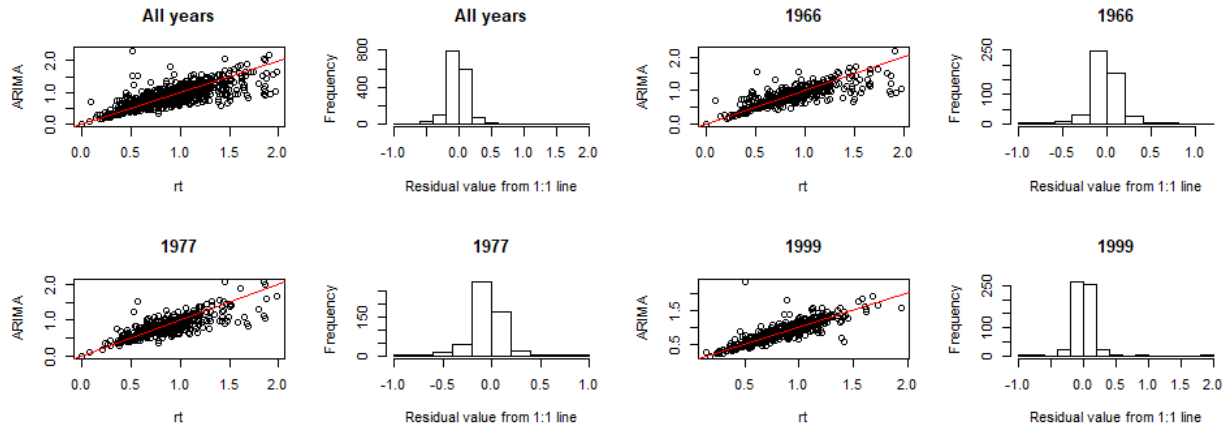


Figure S5. Comparison of  $R_t$  and  $R_{tARIMA}$  results, with residuals, for each drought scenario

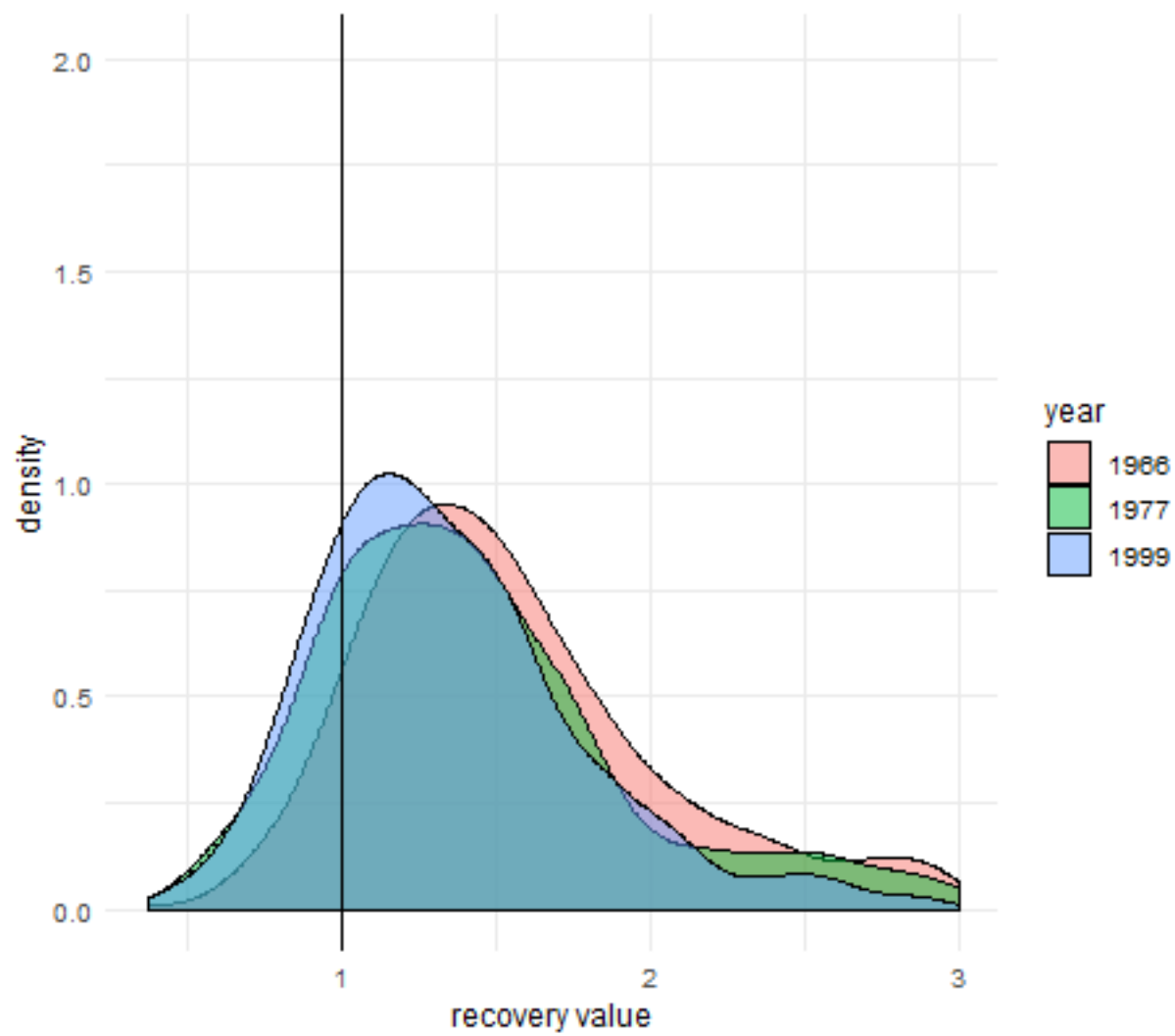


Figure S6. Drought recovery,  $R_c$ , across species for the three focal droughts.

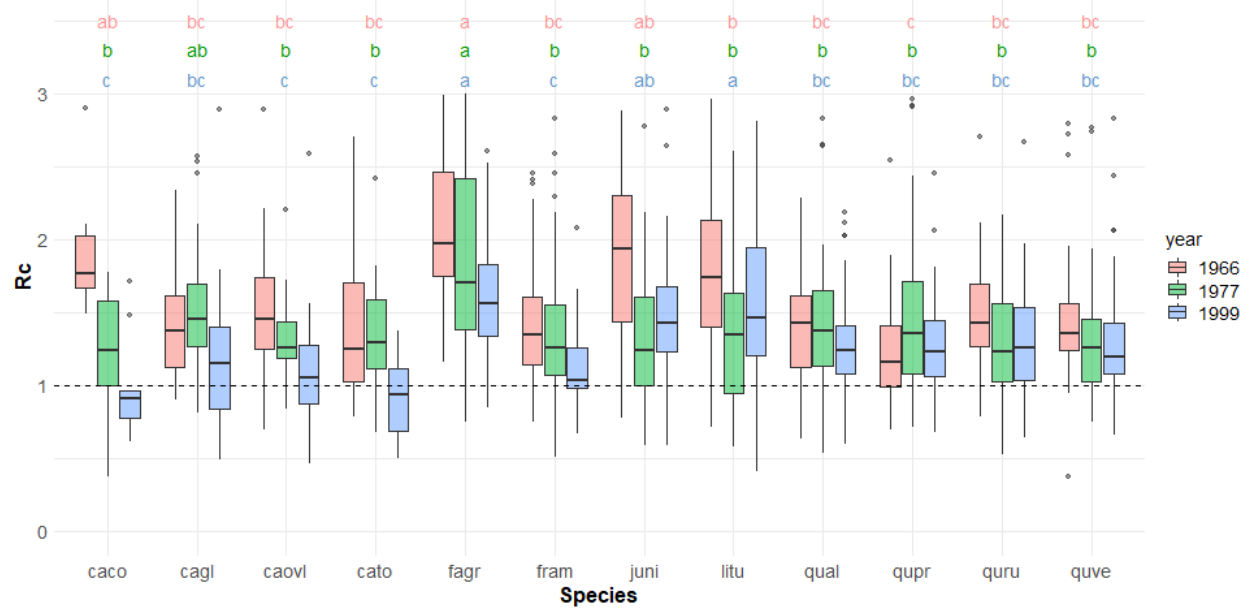


Figure S7. Drought recovery,  $R_c$ , across species for the three focal droughts.

## Appendix S1. Further Package Citations

While there were several R-packages we used for a specific purpose in our methods, numerous packages were immensely helpful for this research behind the scenes. As in all of science, this study is a representation of the work done by both the authors of this paper as well as countless others. While acknowledging everyone is impossible, we want to at least give thanks to those who made this work possible.

R-packages not already cited in the main manuscript include the following, listed alphabetically by corresponding package name:

(Urbanek, 2013; Winston Chang, 2014; Augue, 2017; Wickham, 2017, 2019; Spinu *et al.*, 2018; Arnold, 2019; Barton, 2019; Bivand *et al.*, 2019; Bivand & Rundel, 2019; Bunn *et al.*, 2019; Dowle & Srinivasan, 2019; Fox *et al.*, 2019; Henry & Wickham, 2019; Lefcheck *et al.*, 2019; Perpinan Lamigueiro & Hijmans, 2019; R Core Team, 2019; Wickham & Bryan, 2019; Wickham *et al.*, 2019, 2020a,b; Wilke, 2019; Allaire *et al.*, 2020; Gagolewski *et al.*, 2020; Hijmans, 2020; Kassambara, 2020; Pebesma, 2020; Robinson & Hayes, 2020; Temple Lang, 2020; Wickham & Henry, 2020; Xie, 2020)

Allaire J, Xie Y, McPherson J, Luraschi J, Ushey K, Atkins A, Wickham H, Cheng J, Chang W, Iannone R. **2020**. *Rmarkdown: Dynamic documents for r*.

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